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Task 10 Report

Cyanide Transport Modeling

Escalante Mine
Tailings Impoundment

Enterprise, Utah

Prepared For:

Hecla Mining Company
Coeur d'Alene, Idaho

Prepared By:

Grant, Schreiber and Associates
Coeur d'Alene, Idaho

June 28, 1991

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Engineering • Hydrology • Management
Coeur d'Alene • Denver • Little Rock

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Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

As a follow-up to the Escalante Mine Reclamation Plan, Grant, Schreiber and Associates (GSA) has completed additional studies of the potential for leachate and the movement of cyanide from the tailings impoundment. The work includes modeling of the impoundment to determine the length of time for liquid to penetrate the pond liner and subsequently reach the water table assuming:

- continued use of the pond,
- no reclamation of the pond, and
- reclamation of the pond, as proposed.

In addition, GSA has used available information regarding cyanide attenuation/degradation to assess potential impacts to the local ground-water system. This work is summarized in the following sections.

2. PREVIOUS INVESTIGATION

An investigation was conducted by Fox Consultants, Inc. (Fox) in 1984 to evaluate the potential for seepage migration through the compacted liner and natural foundation soils. The investigation included:

- drilling and sampling at one location within the tailings impoundment to provide a vertical profile of the tailings, compacted liner, and natural foundation materials,
- conducting a laboratory testing program on the retrieved samples to measure moisture content, dry density, specific gravity, and permeability, and
- estimating the potential for seepage migration through the liner during:
  - the original design life of the tailings pond, and
  - a possible extended tailings pond life, including an additional 10 to 15 feet of deposited tailings.

Based upon the field and laboratory investigations, Fox concluded that:

- After approximately 14 months under an average of 10 feet of saturation and an additional 20 months following the activation of the underdrain system, the wetting front did not appear to have penetrated through the liner or into the foundation. The wetting front may have progressed 3 inches, at the most, into the liner, prior to the activation of the underdrain system.

- Theoretical predictions of the time required for the wetting front to penetrate 3 inches into the liner were several orders of magnitude faster than indicated by field observations.
- The underdrain system appeared to have eliminated or significantly reduced the phreatic surface within the tailings, which greatly lowers the potential for seepage migration through the compacted liner.

Based upon these facts and the great depth to the water table, Fox concluded that the potential for seepage migration through the liner and foundation to the ground-water table during and after the design life of the impoundment is extremely small.

3. WATER MOVEMENT

To conduct the present investigation, GSA used the Hydrologic Evaluation of Landfill Performance (HELP) Model (Schroeder, et al., 1983, and Schroeder, 1988) to simulate movement of water through the tailings impoundment for the following conditions:

- during operation,
- after operation without reclamation, and
- with reclamation, as proposed.

The HELP Model requires climatologic data including precipitation, temperature, and solar radiation. For each of the three conditions, GSA used synthetic climate data for Milford, Utah. The synthetic temperature and precipitation calculated by the HELP model were based upon the local mean monthly temperature and precipitation data.

The modeling that GSA performed for the reclamation plan (GSA, 1990) used climatologic data collected at Cedar City, Utah, from 1974 through 1978. This data set was provided with the HELP model. Since this data set only covered a five-year period, GSA opted to use synthetically generated data for Milford, Utah, for the present study. This data set is also provided with the HELP model. The use of these data allowed GSA to conduct the simulation for a period of up to 20 years.

The average precipitation at Cedar City during the period from 1974 through 1978 was 9.76 inches, compared to 10.47 inches for the 20 years of the synthetic data. According to Section A of Notice of Intention to Commence Mining Operations (Ranchers, 1980), the total precipitation is 10 to 15 inches per year. Thus, the synthetic data are within this range. The following sections summarize the HELP model simulations.

3.1 During Operations

GSA used information from previous reports to simulate the tailings impoundment during operations. According to the report by Wright Engineers (Wright, 1980), water was to be deposited in the pond at a rate of 160 gpm or 247.5 acre-feet per year. This rate of inflow is equivalent to approximately 0.15 inches per day, spread over the entire surface area of the pond. To incorporate this inflow into the HELP model, the 0.15 inches per day of water was added to the daily precipitation for the first 10 years of the simulation. For the purpose of the simulation, it was assumed that the average depth of the tailings was 30 feet (Drawing No. 11359 from the Reclamation Plan). The soil profile of the tailings impoundment used to simulate this condition is shown in Table 1. The thickness, porosity, hydraulic conductivity, and initial water content were obtained from Fox Reports (1980 and 1984).

Table 1. Soil profile for operational and pre-reclamation condition.

Layer	Material	Thickness (inches)	Layer Type	Porosity	Hydraulic Conductivity cm/sec	Initial Water Content
1	Tailings	360	Vertical Percolation	0.49	1.9×10^{-5}	30.0%
2	Underdrain	12	Lateral Drainage	0.41	1.0×10^{-3}	13.2%
3	Clay Liner	24	Barrier	0.41	5.67×10^{-7}	15.1%
4	Foundation Soil	3600	Vertical Percolation	0.31	2.44×10^{-5}	5.7%

Table 2 shows the results of the simulation for the 10-years of operation. The precipitation, including water from the mill, ranged from 61.55 to 70.46 inches per year, with an average of 65.67 inches. Evapotranspiration ranged from 46.341 to 49.682 inches per year, with an average of 47.698 inches. This loss represents nearly three quarters of the water entering the pond. Flow from the underdrain, which was returned to the mill, averaged 7.17 inches per year during the 10-year period of operations. Flow from the underdrain began in June of the third year and reached a peak of 14.11 inches in the seventh year. Over the entire operating period, the underdrain flow represented nearly 11 percent of the water entering the pond. However, during years 6 through 10, the underdrain removed an average of 17.3 percent of the total water input, including over 20 percent in the seventh year.

The model predicts that water will begin percolating from the liner in June of the third year, which is the same time that the underdrain begins flowing. The liner maintains a relatively constant seepage of approximately 7.25 inches for years 4 through 10. Percolation through the foundation soils and into ground water occurs every year during the simulation. The percolation to ground water during the first two years is 0.0352 inches. Since both the underdrain and liner seepage were zero, the percolation to ground water, during this time, is the result of natural recharge. The amount of percolation to ground water subsequently increases in each of the following years.

3.2 After Operations With No Reclamation

The HELP model was used to simulate the tailings impoundment after operations were ceased. This simulation was performed for the 10 years immediately following operation of the impoundment. Table 2 shows that, during this period, the precipitation ranged from 5.22 to 16.32 inches, with an average of 10.01 inches. Evapotranspiration during this period ranged from 5.515 to 16.722, with an average of 10.047 inches. This accounts for a loss of over 100 percent of the water input into the system. During this time, however, there is still moisture in the soil layers that migrates through the liner and percolates to ground water. The amount of percolation through the liner is rapidly decreasing during this period, while the percolation to ground water is slowly increasing as water moves downward through the unsaturated zone.

Table 2. HELP Model results for operational and pre-reclamation conditions.

Year	Precipitation (inches)	Runoff (inches)	Evapotrans (inches)	Underdrain (inches)	Percolation Liner (inches)	Percolation Groundwater (inches)
During operations						
1	62.99	0.000	47.065	0.0000	0.0000	0.0352
2	64.64	0.000	48.269	0.0000	0.0000	0.0352
3	65.98	0.000	46.341	0.0413	3.1375	0.0361
4	61.55	0.000	47.023	5.9464	7.1791	0.0436
5	64.58	0.000	48.132	7.3776	7.1866	0.0540
6	70.46	0.000	49.682	11.9536	7.2816	0.0665
7	70.20	0.000	47.673	14.1143	7.3240	0.0812
8	66.72	0.000	48.565	11.9268	7.2999	0.0985
9	62.25	0.000	47.724	9.1831	7.2225	0.1177
10	67.34	0.000	46.509	11.2019	7.2655	0.1400
Average	65.67	0.000	47.698	7.1745	5.3897	0.0708
St. Dev	3.083	0.000	1.017	5.4693	3.1171	0.0375
Percent	100.00	0.00	72.63	10.92	8.21	0.11
After operations, with no reclamation						
11	8.79	0.000	10.556	4.2219	6.8600	0.1650
12	12.15	0.000	10.907	0.0062	3.7856	0.1861
13	12.96	0.000	14.181	0.0023	2.3236	0.1972
14	7.68	0.000	6.902	0.0012	1.6687	0.2050
15	8.78	0.000	8.528	0.0007	1.2816	0.2107
16	9.02	0.000	8.727	0.0005	1.0408	0.2156
17	16.32	0.000	16.722	0.0003	0.8709	0.2185
18	12.00	0.000	12.272	0.0002	0.7495	0.2213
19	5.22	0.000	5.515	0.0002	0.6572	0.2236
20	7.20	0.000	6.161	0.0001	0.5862	0.2261
Average	10.01	0.000	10.047	0.4234	1.9824	0.2069
St. Dev	3.288	0.000	3.608	1.3347	1.9747	0.0193
Percent	100.00	0.00	100.35	4.23	19.80	2.07
Years 1 through 20						
Average	37.84	0.000	28.873	3.7989	3.6860	0.1389
St. Dev	28.721	0.000	19.486	5.1969	3.0830	0.0756
Percent	100.00	0.00	76.30	10.04	9.74	0.37

3.3 After Reclamation

GSA also used the HELP model to simulate the tailings impoundment after reclamation. The impoundment was simulated using the seven layers proposed in the reclamation plan. The configuration and properties of these layers are shown in Table 3. Layers 1 through 3 represent the topsoil, subsoil, and clay cap, respectively. The properties of these layers were selected based upon typical values for the soils present at the site. Layers 4 through 7 represent the tailings, underdrain, clay liner, and foundation soil, respectively.

Table 3. Soil profile for the reclaimed tailings impoundment.

Layer	Material	Thickness (inches)	Layer Type	Porosity	Hydraulic Conductivity cm/sec	Initial Water Content
1	Topsoil	4	Vertical Percolation	0.40	$1.2X10^{-4}$	5.0%
2	Subsoil	14	Lateral Drainage	0.42	$1.0X10^{-5}$	5.0%
3	Clay Cap	6	Barrier	0.43	$1.0X10^{-7}$	10.0%
4	Tailings	360	Vertical Percolation	0.49	$1.9X10^{-5}$	30.0%
5	Underdrain	12	Lateral Drainage	0.41	$1.0X10^{-3}$	13.2%
6	Clay Liner	24	Barrier	0.41	$5.67X10^{-7}$	15.1%
7	Foundation Soil	3600	Vertical Percolation	0.31	$2.44X10^{-5}$	5.7%

Table 4 shows the results of the simulation for a period of 20 years after reclamation. The precipitation during this period ranged from 5.22 to 16.32 inches, with an average of 10.47 inches. Surface runoff from the cap ranged from 0.002 to 1.396 inches, with an average of 0.367 inches. This accounts for a loss of 3.5 percent of the water input to the system. Evapotranspiration during this period ranged from 5.552 to 15.482 inches, with an average of 9.945 inches. This results in a loss of over 95 percent of the water entering the system. The model also shows an average of 0.0839 inches per year penetrating the 6-inch clay cap and entering the tailings. Assuming that the tailings were initially dry, it would take approximately 1,660 years to saturate the tailings at this rate of seepage. If the tailings moisture is 30 percent, as observed during operations, it will take approximately 270 years to saturate the tailings. Since the tailings have been draining since operations were ceased, the water content will be much less than 30 percent. For instance, if the water content of the tailings was reduced to 10 percent, the time required to saturate the tailings at an inflow rate of 0.0839 inches per year is nearly 1,200 years.

Most importantly, the model shows no liquid reaching the underdrain, percolating through the liner, or percolating to ground water during the 20-year period following reclamation. The lack of ground-water recharge, compared to cases without reclamation, is attributed to the reduced water supply resulting from:

- the absence of the process water entering the impoundment, and
- reduced infiltration resulting from encapsulation of the tailings.

Table 4. HELP Model results for Escalante Mine after reclamation.

Year	Precipitation (inches)	Runoff (inches)	Evapotrans (inches)	Cap Drain (inches)	Cap Percolation (inches)	Underdrain (inches)	Percolation: Liner (inches)	Percolation: Groundwater (inches)
1	8.24	0.120	7.408	0.0000	0.0094	0.0000	0.0000	0.0000
2	9.89	0.130	9.302	0.0000	0.0000	0.0000	0.0000	0.0000
3	11.23	0.177	10.960	0.0001	0.3516	0.0000	0.0000	0.0000
4	6.80	0.002	7.371	0.0000	0.0000	0.0000	0.0000	0.0000
5	9.83	0.315	8.199	0.0000	0.0000	0.0000	0.0000	0.0000
6	15.71	0.648	15.482	0.0000	0.0000	0.0000	0.0000	0.0000
7	15.45	0.588	14.503	0.0000	0.0000	0.0000	0.0000	0.0000
8	11.97	0.436	11.411	0.0000	0.1912	0.0000	0.0000	0.0000
9	7.50	0.007	8.679	0.0000	0.0000	0.0000	0.0000	0.0000
10	12.59	1.396	10.264	0.0000	0.0000	0.0000	0.0000	0.0000
11	8.79	0.049	9.551	0.0000	0.2531	0.0000	0.0000	0.0000
12	12.15	0.243	10.797	0.0000	0.0000	0.0000	0.0000	0.0000
13	12.96	0.645	12.912	0.0002	0.5022	0.0000	0.0000	0.0000
14	7.68	0.470	6.778	0.0000	0.0000	0.0000	0.0000	0.0000
15	8.78	0.145	8.338	0.0000	0.0000	0.0000	0.0000	0.0000
16	9.02	0.065	8.099	0.0000	0.0000	0.0000	0.0000	0.0000
17	16.32	1.341	15.739	0.0002	0.3713	0.0000	0.0000	0.0000
18	12.00	0.447	11.595	0.0000	0.0000	0.0000	0.0000	0.0000
19	5.22	0.039	5.552	0.0000	0.0000	0.0000	0.0000	0.0000
20	7.20	0.074	5.966	0.0000	0.0000	0.0000	0.0000	0.0000
Average	10.47	0.367	9.945	0.0000	0.0839	0.0000	0.0000	0.0000
St Dev	3.137	0.404	2.991	0.0001	0.1579	0.0000	0.0000	0.0000
Percent	100.00	3.50	95.02	0.00	0.80	0.00	0.00	0.00

4. CYANIDE MOVEMENT

GSA used information on cyanide movement, attenuation, and degradation from a study by Resource Recovery and Conservation Consultants (R^2C^2, 1989) to investigate the potential impacts of cyanide at the Escalante Site. Among the information developed during the course of the R^2C^2 study was a model of cyanide solute transport through a clay lined pond. The model was developed at Colorado State University by Simon Lorentz and David McWhorter.

GSA used this model to estimate the time required for liquid and solute to reach the ground-water table, which is approximately 300 feet below the bottom of the impoundment. Data contained in the reclamation plan and Fox Reports (1980 and 1984), supplemented with data from the R^2C^2 study, were used to model the system. The parameters required by the model, and the values for these parameters, are briefly summarized below:

- Depth to the water table (D_f) - 300 feet (Fox, 1980 and GSA, 1990).
- Depth of Ponding (D_w) - considered to be the maximum daily head on the pond liner (2.3 inches), as calculated by the HELP model. Other values were used to simulate extreme conditions.
- Thickness of the clay liner (D_l) - 2 feet (Fox 1980).
- Hydraulic conductivity of the liner (K_l) - 5.67×10^{-7} cm/sec (Fox, 1980).
- Hydraulic conductivity of the foundation (K_o) - 2.44×10^{-5} cm/s (Fox, 1980)
- Alpha parameter of the foundation (α) - defines the unsaturated hydraulic conductivity of the foundation soil (K_f) as a function of K_o and matric potential (h) as: $K_f = K_o e^{-\alpha h}$. Values of 0.03, 0.05, and 0.055 cm^{-1} were selected for comparison, based upon data presented by R^2C^2 (1989).
- Distribution Coefficient (K_d) - Values of 0.3 and 0.7 cm^3/g were selected for comparison, based upon data presented by R^2C^2 (1989).
- Bulk Density (ρ_b) - 1.45 g/cm^3 (Fox, 1984).
- Henry's Law Constant (K_H) - 0.0043 (R^2C^2, 1989).
- Residual Water Content (θ_r) - Values of 0.10, 0.15, and 0.20 were selected for comparison, based upon data presented by R^2C^2 (1989).
- Saturated water content (θ_s) - 0.31 (same as porosity).

- Tortuosity Constant (m) - Values of 0, 1, and 2 were selected for comparison, based upon data presented by R^2C^2 (1989).
- Concentration of Effluent (C_o) - The concentrations of cyanide in two water samples collected from the underdrain on October 4, 1990 (GSA, 1990) were 186 and 191 mg/l. Thus, a representative value of C_o=190 mg/l was used in the model.

Table 5 shows the results of the CSU model for 14 cases. The 14 cases represent a sensitivity analysis that was performed because of the uncertainty of some of the parameters. These parameters include K_d, α, θ_r, m, and D_w. The values used for these parameters were estimated based upon guidance provided in the R^2C^2 report. For Cases 2 through 14, the shaded value in Table 5 has been changed, while holding the other parameters constant.

Case 1 represents GSA's best estimate of the actual conditions at the Escalante site. This case results in a required time of nearly 59,600 days, or more that 160 years, for the solute to reach ground water. At this time, the model begins computing the mass loading of cyanide in g/m² to the aquifer. A drawback to the model is the assumption that the cyanide concentration in the plume is constant. Thus, the mass loading to the aquifer increases linearly with time, based upon the effluent concentration (C_o) and flow rate. Therefore, the model is not accounting for the degradation of cyanide.

The parameters that have the greatest affect on the time for the solute to reach groundwater are K_d (Cases 1,2, and 3) and α (Cases 1, 4, and 5). Case 3 (K_d=0), which represents no adsorption of the solute onto the solid matrix, is equivalent to the movement of the water through the foundation soil. The predicted time for the solute to reach ground water for this case is nearly 20,900 days or 57 years. Increasing K_d from 0 to 0.7 increases this time to over 300 years. Decreasing α from 0.05 to 0.03 decreased the travel time by approximately 32 years, while increasing α from 0.05 to 0.055 increased the travel time by 6 years. Changing θ_r and m resulted in relatively small changes in the travel time, as evidenced by Cases 6 through 9. Changing D_w over the range of values indicated by the HELP model showed small changes in the travel time (Cases 10 and 11). Cases 12 through 14 shows the effect of a larger head (1 to 10 feet) on the liner. Case 12 represents the underdrain layer under a saturated condition (1 foot of head on the liner). Case 13 represents approximately 3 feet of head on the liner. These two cases resulted in solute travel times of 112 and

Table 5. Modeling Results from CSU Cyanide Transport Model.

Case 1

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	1.83
Dl, m	0.6	10000	0	15.55
Kl, cm/s	5.67E−07	20000	0	31.11
Ko, cm/s	2.44E−05	40000	0	62.22
Alpha	0.05	50000	0	76.86
Kd, cm3/g	0.3	59500	0	91.5
Pb, g/cm3	1.45	60000	69.9	91.5
Kh	0.0043	80000	3989.9	91.5
Θr	0.1	100000	7910	91.5
Θs	0.3	150000	17710	91.5
m	1	200000	27510	91.5
Co, mg/l	190			
Travel time*	59644			

Case 2

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	0.92
Dl, m	0.6	10000	0	9.15
Kl, cm/s	5.67E−07	20000	0	17.38
Ko, cm/s	2.44E−05	40000	0	33.85
Alpha	0.05	60000	0	49.41
Kd, cm3/g	0.7	80000	0	65.88
Pb, g/cm3	1.45	100000	0	82.35
Kh	0.0043	110000	0	90.59
Θr	0.1	111000	0	91.5
Θs	0.3	111500	37.1	91.5
m	1	120000	1703.2	91.5
Co, mg/l	190	150000	7583.2	91.5
Travel time*	111310	200000	17383.2	91.5

Case 3

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	5.49
Dl, m	0.6	10000	0	44.83
Kl, cm/s	5.67E−07	20000	0	87.84
Ko, cm/s	2.44E−05	20900	1.3	91.5
Alpha	0.05	25000	804.9	91.5
Kd, cm3/g	0	30000	1784.9	91.5
Pb, g/cm3	1.45	40000	3745	91.5
Kh	0.0043	50000	5705	91.5
Θr	0.1	100000	15505	91.5
Θs	0.3	200000	35105	91.5
m	1			
Co, mg/l	190			
Travel time*	20893			

Case 4

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	2.75
Dl, m	0.6	10000	0	20.13
Kl, cm/s	5.67E−07	20000	0	38.43
Ko, cm/s	2.44E−05	40000	0	76.86
Alpha	0.03	47000	0	90.59
Kd, cm3/g	0.3	48000	33.7	91.5
Pb, g/cm3	1.45	50000	526.8	91.5
Kh	0.0043	100000	12854	91.5
Θr	0.1	150000	25181	91.5
Θs	0.3	200000	37509	91.5
m	1			
Co, mg/l	190			
Travel time*	47863			

*Time in days for solute front to reach ground water.

Table 5. Modeling Results from CSU Cyanide Transport Model (continued).

Case 5

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	1.83
Dl, m	0.6	10000	0	15.55
Kl, cm/s	5.67E-07	20000	0	30.19
Ko, cm/s	2.44E-05	40000	0	59.47
Alpha	0.055	60000	0	88.76
Kd, cm3/g	0.3	61000	0	90.59
Pb, g/cm3	1.45	61900	1.1	91.5
Kh	0.0043	70000	1528.6	91.5
Θr	0.1	100000	7186	91.5
Θs	0.3	150000	16615	91.5
m	1	200000	26044	91.5
Co, mg/l	190			
Travel time*	61894			

Case 6

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	1.83
Dl, m	0.6	10000	0	15.55
Kl, cm/s	5.67E-07	20000	0	30.19
Ko, cm/s	2.44E-05	40000	0	60.39
Alpha	0.05	60000	0	90.59
Kd, cm3/g	0.3	61000	0	91.5
Pb, g/cm3	1.45	62000	182.7	91.5
Kh	0.0043	80000	3710.7	91.5
Θr	0.15	100000	7630.7	91.5
Θs	0.3	150000	17430.8	91.5
m	1	200000	27231	91.5
Co, mg/l	190			
Travel time*	61068			

Case 7

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	1.83
Dl, m	0.6	10000	0	15.55
Kl, cm/s	5.67E-07	20000	0	30.19
Ko, cm/s	2.44E-05	40000	0	59.47
Alpha	0.05	60000	0	88.76
Kd, cm3/g	0.3	62000	0	91.5
Pb, g/cm3	1.45	62500	1.5	91.5
Kh	0.0043	80000	3431.5	91.5
Θr	0.2	100000	7351.5	91.5
Θs	0.3	150000	17151.6	91.5
m	1	200000	26951.7	91.5
Co, mg/l	190			
Travel time*	62493			

Case 8

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	1.83
Dl, m	0.6	10000	0	16.47
Kl, cm/s	5.67E-07	20000	0	32.02
Ko, cm/s	2.44E-05	40000	0	64.05
Alpha	0.05	57000	0	91.5
Kd, cm3/g	0.3	57600	13.6	91.5
Pb, g/cm3	1.45	60000	484	91.5
Kh	0.0043	80000	4404	91.5
Θr	0.1	100000	8324.1	91.5
Θs	0.3	150000	18124.2	91.5
m	0	200000	27924.3	91.5
Co, mg/l	190			
Travel time*	57531			

*Time in days for solute front to reach ground water.

Table 5. Modeling Results from CSU Cyanide Transport Model (continued).

Case 9

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.06	1000	0	1.83
Dl, m	0.6	10000	0	15.55
Kl, cm/s	5.67E-07	20000	0	30.19
Ko, cm/s	2.44E-05	40000	0	60.39
Alpha	0.05	60000	0	90.59
Kd, cm3/g	0.3	61000	26.3	91.5
Pb, g/cm3	1.45	80000	3750	91.5
Kh	0.0043	100000	7670	91.5
Θr	0.1	150000	17470	91.5
Θs	0.3	200000	27270	91.5
m	2			
Co, mg/l	190			
Travel time*	60866			

Case 10

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.03	1000	0	1.83
Dl, m	0.6	10000	0	15.55
Kl, cm/s	5.67E-07	20000	0	31.11
Ko, cm/s	2.44E-05	40000	0	60.39
Alpha	0.05	60000	0	90.59
Kd, cm3/g	0.3	61000	30.7	91.5
Pb, g/cm3	1.45	80000	3678.5	91.5
Kh	0.0043	100000	7518.3	91.5
Θr	0.1	150000	17118	91.5
Θs	0.3	200000	26717	91.5
m	1			
Co, mg/l	190			
Travel time*	60840			

Case 11

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0	1000	0	1.83
Dl, m	0.6	10000	0	15.55
Kl, cm/s	5.67E-07	20000	0	30.19
Ko, cm/s	2.44E-05	40000	0	59.47
Alpha	0.05	60000	0	88.76
Kd, cm3/g	0.3	62000	0	91.5
Pb, g/cm3	1.45	63000	172.5	91.5
Kh	0.0043	80000	3368.3	91.5
Θr	0.1	100000	7128.1	91.5
Θs	0.3	150000	16527.5	91.5
m	1	200000	25927	91.5
Co, mg/l	190			
Travel time*	62083			

Case 12

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	0.305	1000	0	2.75
Dl, m	0.6	10000	0	22.87
Kl, cm/s	5.67E-07	20000	0	45.75
Ko, cm/s	2.44E-05	30000	0	67.71
Alpha	0.05	40000	0	90.59
Kd, cm3/g	0.3	41000	63.1	91.5
Pb, g/cm3	1.45	50000	2125.5	91.5
Kh	0.0043	60000	4417.1	91.5
Θr	0.1	80000	9000.3	91.5
Θs	0.3	100000	13583.5	91.5
m	1	150000	25041.5	91.5
Co, mg/l	190	200000	36449.5	91.5
Travel time*	40724			

*Time in days for solute front to reach ground water.

Table 5. Modeling Results from CSU Cyanide Transport Model (continued).

Case 13

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	1	1000	0	2.75
Dl, m	0.6	10000	0	25.62
Kl, cm/s	5.67E-07	20000	0	50.32
Ko, cm/s	2.44E-05	30000	0	75.95
Alpha	0.05	36000	0	90.59
Kd, cm3/g	0.3	37000	133.3	91.5
Pb, g/cm3	1.45	40000	1111.4	91.5
Kh	0.0043	60000	7632.1	91.5
Θr	0.1	80000	14152.8	91.5
Θs	0.3	100000	20673.6	91.5
m	1	150000	36975.4	91.5
Co, mg/l	190	200000	53277.2	91.5
Travel time*	36591			

Case 14

Parameter		Time	Mass Loading	Solute Depth
Df, m	91.5	100	0	0.92
Dw, m	3.048	1000	0	5.49
Dl, m	0.6	10000	0	47.58
Kl, cm/s	5.67E-07	19500	0	91.5
Ko, cm/s	2.44E-05	20000	236.9	91.5
Alpha	0.05	40000	12709.3	91.5
Kd, cm3/g	0.3	60000	25181.8	91.5
Pb, g/cm3	1.45	80000	37654.3	91.5
Kh	0.0043	100000	50126.8	91.5
Θr	0.1	150000	81307.9	91.5
Θs	0.3	200000	112489.	91.5
m	1			
Co, mg/l	190			
Travel time	19602			

*Time in days for solute front to reach ground water.

100 years, respectively. Case 14 represents the start of operations at the mine when the impoundment operated at an average saturation of 10 feet for 14 months prior to the activation of the underdrain. Under a constant saturation of 10 feet, the time required for the solute to reach the water table is approximately 54 years. After 14 months at a saturated depth of 10 feet, the predicted depth of the solute front is 8.4 feet. However, this is much greater than the actual conditions that were observed by Fox in 1984, as described in Section 2.

5. CYANIDE IMPACT

The calculated travel time for ground-water to move from beneath the impoundment to the downgradient monitoring well, located approximately 1,000 feet from the impoundment, is 4,750 years (GSA, 1990). If adsorption is considered, the time for solute to reach the monitoring well will be much greater. The retardation factor, R_d, can be used to compute the solute travel time with the presence of adsorption. The retardation factor is defined as: $R_d = 1 + (\rho_b/\phi)K_d$, where ϕ is the total porosity. For ρ_b=1.45 g/cm³, ϕ=0.31, and K_d=0.3, R_d is equal to 2.4. Thus, the solute travel time will be 2.4 times the ground-water gravel time, or 11,400 years to reach the downgradient monitoring well. As shown in Figure 1, the nearest downgradient wells (WL-14 and WQ-2) are approximately 6,000 feet from the tailings impoundment. Using water level data from wells TMW-2 and D-2 to calculate the gradient and $K_o = 2.44 \times 10^{-5}$, the travel time to wells WL-14 and WQ-2 is approximately 14,600 years. Considering the affect of adsorption, the time required for solute to reach these wells is more than 35,000 years.

As stated in Section 4, GSA's best estimate of the travel time of solute through the unsaturated zone is over 160 years. This travel time through the unsaturated zone is insignificant when compared to the magnitude of the ground water and solute travel times. However, according to the R^2C^2 study, cyanide degradation can occur in both the saturated and unsaturated zones, but particularly in the unsaturated zone. Thus, the 160-year solute travel time through the unsaturated zone may provide a significant reduction in cyanide concentration.

Cyanide attenuation/degradation can occur by many mechanisms including: volatilization, chelation, precipitation, adsorption, oxidation to cyanate, and biodegradation. In a large column test that was operated for 81 days, R^2C^2 obtained the following results:

- approximately 56 percent of the cyanide added to the unsaturated column was oxidized to cyanate,
- approximately 10 percent of the cyanide added to the column was volatilized to HCN gas.

Thus, attenuation of cyanide by natural processes can be significant in a relatively short period of time.

Clay liners can be effective in containing and retarding cyanide movement. Projections from column tests subjected to a 3-foot hydraulic head indicated that two feet of compacted shale would contain weak-acid dissociable cyanide over the 10- to 20-year life of a facility (R^2C^2, 1989). This projection was calculated using an assumed compacted shale hydraulic conductivity of 10^{-7} cm/sec. Using this conductivity and a 3-foot hydraulic head, a solution penetration of about 8 inches per year was calculated (R^2C^2, 1989). However, the cyanide front had moved only slightly more than four inches after six pore volumes had passed through the column. At a solution penetration of 8-inches per year, it would require 18 years for six pore volumes to migrate through a 24-inch thick liner. Since the underdrain at the Escalante site kept the hydraulic head to a minimum (Fox, 1984), the wetting front and cyanide front would be much slower.

6. CONCLUSIONS

As was the case with the Fox report in 1984, model predictions from the current study over estimate the rate of seepage into the clay liner and foundation soils. Observed conditions at the Escalante site showed that the wetting front had penetrated no more than 3 inches, if any, into the clay liner after 14 months under a saturated depth of 10 feet. Model predictions by GSA show the wetting front penetrating over 8 feet during this time. Thus, the results of this study appear to be very conservative with respect to downward movement of the wetting front.

Based upon the relatively isolated location of the tailings facility (i.e., the distance to downgradient wells), the unlikelihood of seepage from the pond (Fox, 1984), the great depth to the water table, the large time required for contaminants to move off-site (if they reach ground water), and the natural attenuation/degradation of cyanide, the likelihood of a significant impact of cyanide on the ground water system in the vicinity of the Escalante site is very small.

7. REFERENCES

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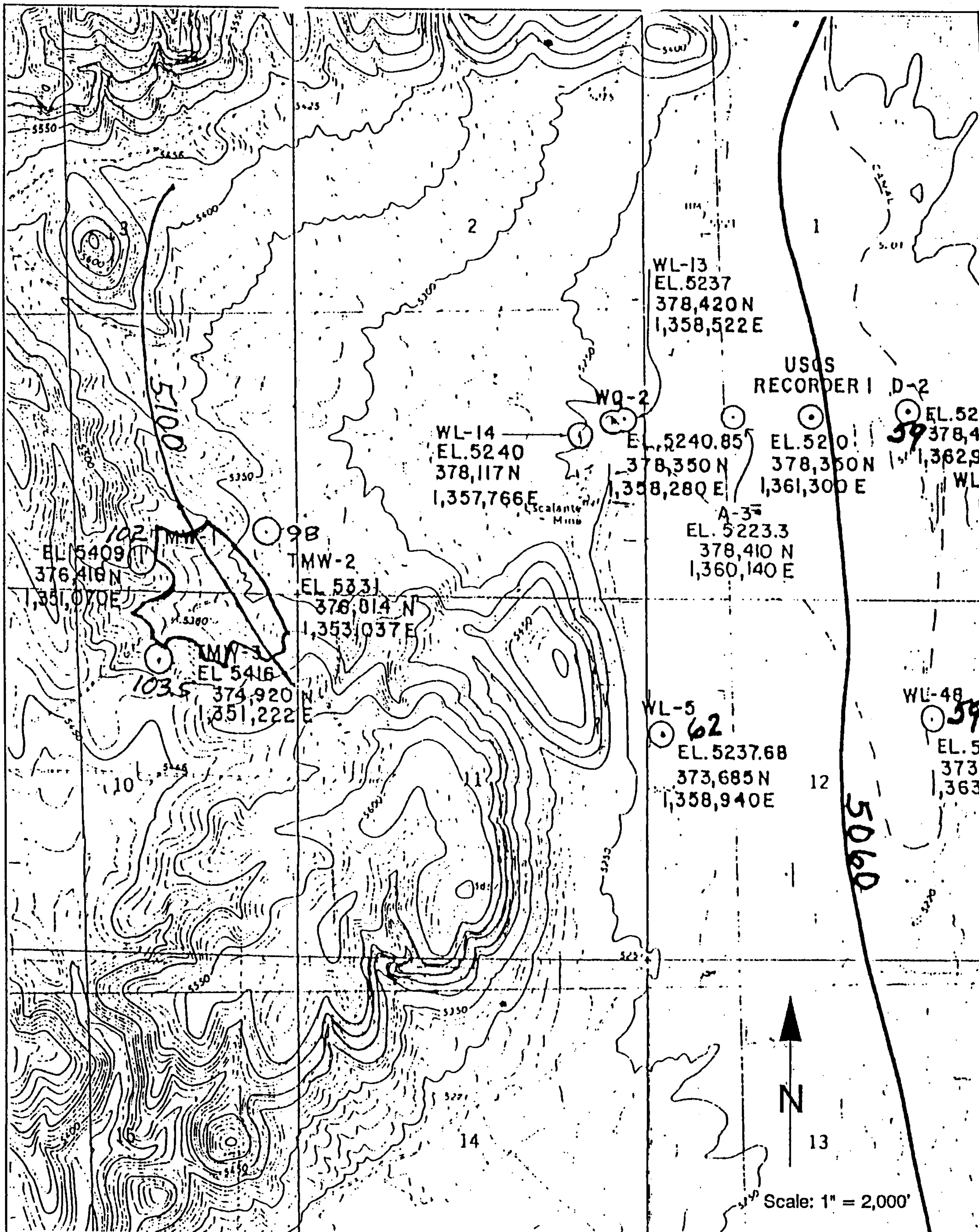

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Figure 1
September 1990 Ground-Water Contours

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Mine Permit Number M021004 Mine Name Escalante Silver
Operator Helca Mining Co Date August 28, 1991
TO ______________ FROM ______________

__CONFIDENTIAL __BOND CLOSURE __LARGE MAPS X EXPANDABLE
__MULTIPUL DOCUMENT TRACKING SHEET __NEW APPROVED NOI
__AMENDMENT _OTHER______________

Description YEAR-Record Number

__NOI X Incoming __Outgoing __Internal __Superceded

Cyanide Transport Modeling
Tailings Impoundment

__NOI __Incoming __Outgoing __Internal __Superceded

__NOI __Incoming __Outgoing __Internal __Superceded

__NOI __Incoming __Outgoing __Internal __Superceded

__TEXT/ 81/2 X 11 MAP PAGES __11 X 17 MAPS __LARGE MAP

COMMENTS: ______________

CC: ______________